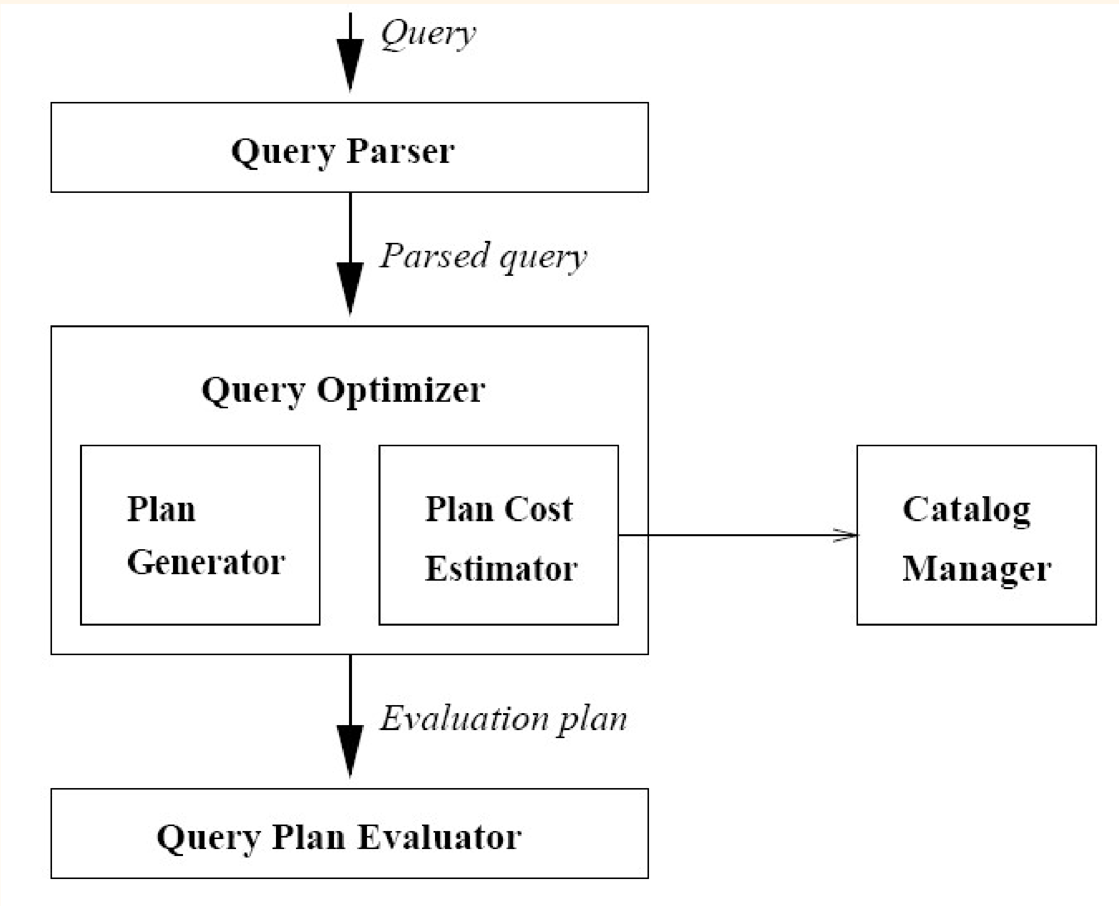
Relational Query Optimization

Chapter 15

Overview of Query Optimization



- *Goal of optimization:* To find more efficient plans that compute the same answer for a given query.
- Ideally: Want to find best plan. Practically: Avoid worst plans!

Schema for Examples

Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)
Reserves (*sid*: integer, *bid*: integer, *day*: dates, *rname*: string)

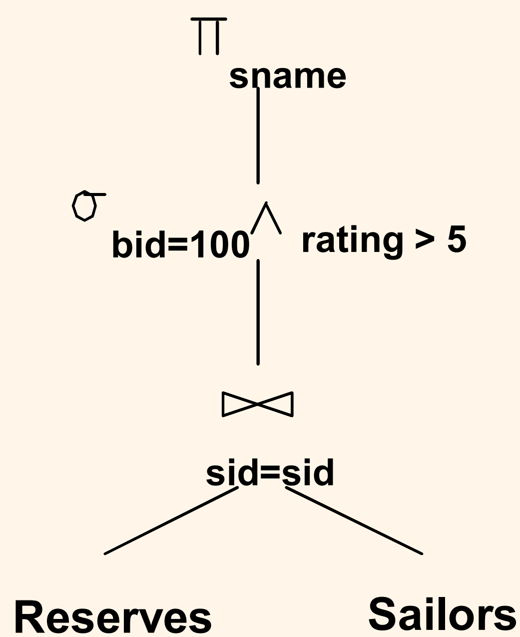
- Reserves:
  - Each tuple is 40 bytes long, 100 tuples per page, 1000 pages.
- Sailors:
  - Each tuple is 50 bytes long, 80 tuples per page, 500 pages.

Motivating Example

SELECT S.sname
FROM Reserves R, Sailors S WHERE R.sid=S.sid AND
R.bid=100 AND S.rating>5

$$\pi_{sname}(\sigma_{bid=100 \wedge rating>5}(Reserves \bowtie_{sid=sid} Sailors))$$

Query Expressed as a Relational Algebra Tree:



Motivating Example

SELECT S.sname
FROM Reserves R, Sailors S WHERE R.sid=S.sid AND
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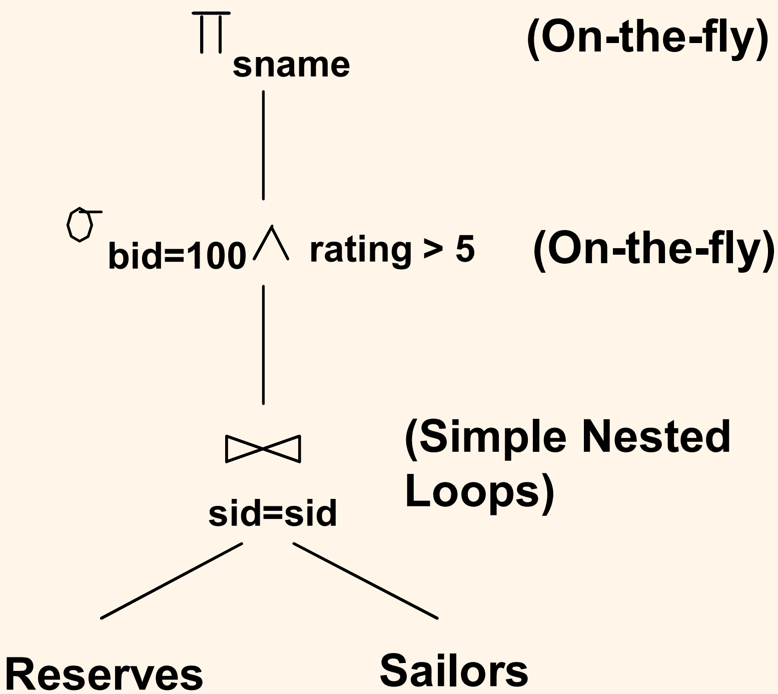
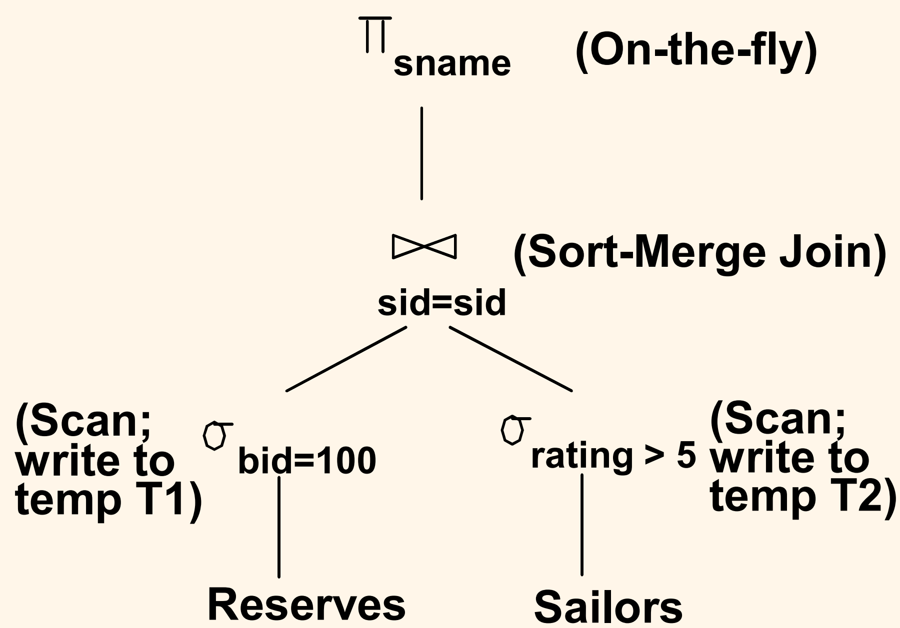
Plan 1:



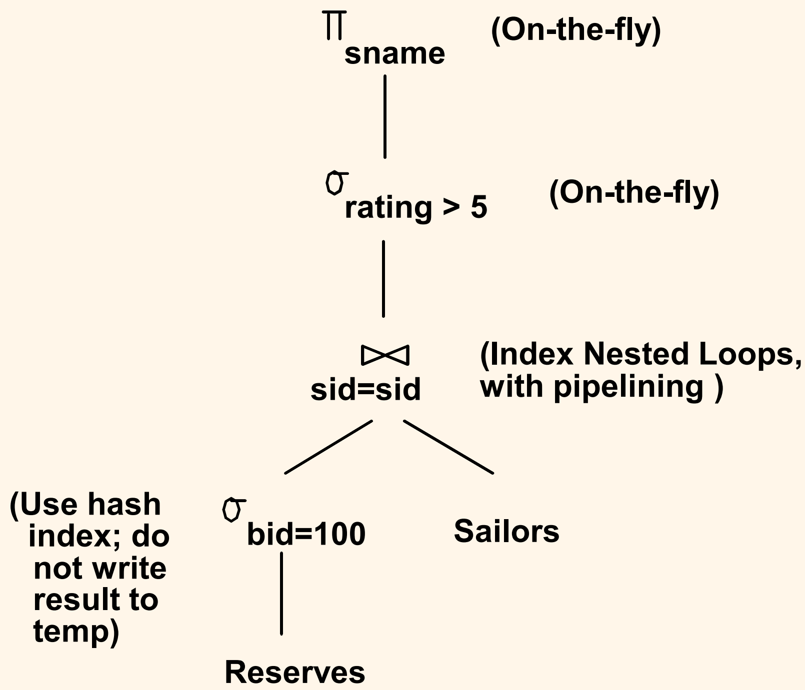
Plan 2:



Motivating Example

SELECT S.sname
FROM Reserves R, Sailors S WHERE R.sid=S.sid AND
R.bid=100 AND S.rating>5

Plan 3:



Relational Algebra Equivalences

- Allow us to choose different join orders and to \`push' selections and projections ahead of joins.
- *Selections*: $\sigma_{c1 \wedge \ldots \wedge cn}(R) \equiv \sigma_{c1}(\ \ldots\ \sigma_{cn}(R))$ *(Cascade)*

  $\sigma_{c1}(\sigma_{c2}(R)) \equiv \sigma_{c2}(\sigma_{c1}(R))$ *(Commutative)*
- *Projections:* $\pi_{a1}(R) \equiv \pi_{a1}(\ \ldots(\pi_{an}(R)))$ *(Cascade)*
- *Joins:* $R \bowtie (S \bowtie T) \equiv (R \bowtie S) \bowtie T$ *(Associative)*

  $(R \bowtie S) \equiv (S \bowtie R)$ *(Commutative)*

Enumeration of Alternative Plans

- There are two main cases:
  - Single-relation plans
  - Multiple-relation plans
- For queries over a single relation, queries consist of a combination of selects, projects, and aggregate ops:
  - Each available access path (file scan / index) is considered, and the one with the least estimated cost is chosen.
  - The different operations are essentially carried out together (e.g., if an index is used for a selection, projection is done for each retrieved tuple, and the resulting tuples are *pipelined* into the aggregate computation).

Cost Estimation

- For each plan considered, must estimate cost:
  - Must estimate *cost* of each operation in plan tree.
    - Depends on input cardinalities.
    - We've already discussed how to estimate the cost of operations (sequential scan, index scan, joins, etc.)
  - Must also estimate *size of result* for each operation in tree!
    - Use information about the input relations.
    - For selections and joins, assume independence of predicates.

Statistics and Catalogs

- Need information about the relations and indexes involved. ***Catalogs*** typically contain at least:
  - # tuples (NTuples) and # pages (NPages) for each relation.
  - # distinct key values (NKeys) and NPages for each index.
  - Index height, low/high key values (Low/High) for each tree index.
- Catalogs updated periodically.
  - Updating whenever data changes is too expensive; lots of approximation anyway, so slight inconsistency ok.
- More detailed information (e.g., histograms of the values in some field) are sometimes stored.

Cost Estimates for Single-Relation Plans

- Sequential scan of file:
  - *NPages(R)*.
- *Reduction factor (RF)* associated with each *term* reflects the impact of the *term* in reducing result size.
- Index I on primary key matches selection:
  - *Cost is Height(I)+1 for a B+ tree, about 1.2 for hash index.*
- Clustered index I matching one or more selects:
  - *(NPages(I)+NPages(R)) * product of RF's of matching selects.*
- Non-clustered index I matching one or more selects:
  - *(NPages(I)+NTuples(R)) * product of RF's of matching selects.*

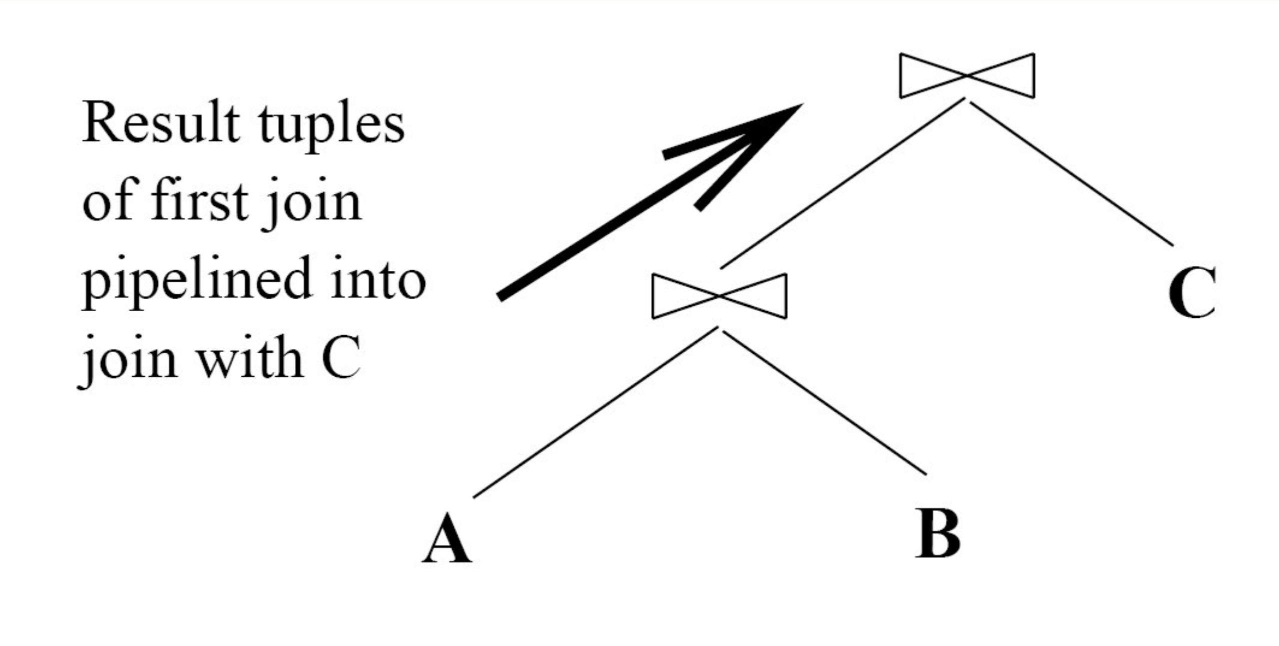
Example

```
SELECT S.sid
FROM Sailors S
WHERE S.rating=8
```

- Doing a file scan:
  - We retrieve all file pages (500).
- If we have an index on *rating*:
  - (1/NKeys(I)) * NTuples(R) = (1/10) * 40000 tuples retrieved.
  - Clustered index: (1/NKeys(I)) * (NPages(I)+NPages(R)) = (1/10) * (50+500) pages are retrieved. (This is the ***cost***.)
  - Unclustered index: (1/NKeys(I)) * (NPages(I)+NTuples(R)) = (1/10) * (50+40000) pages are retrieved.
- If we have an index on *sid*:
  - Would have to retrieve all tuples/pages. With a clustered index, the cost is 50+500, with unclustered index, 50+40000.

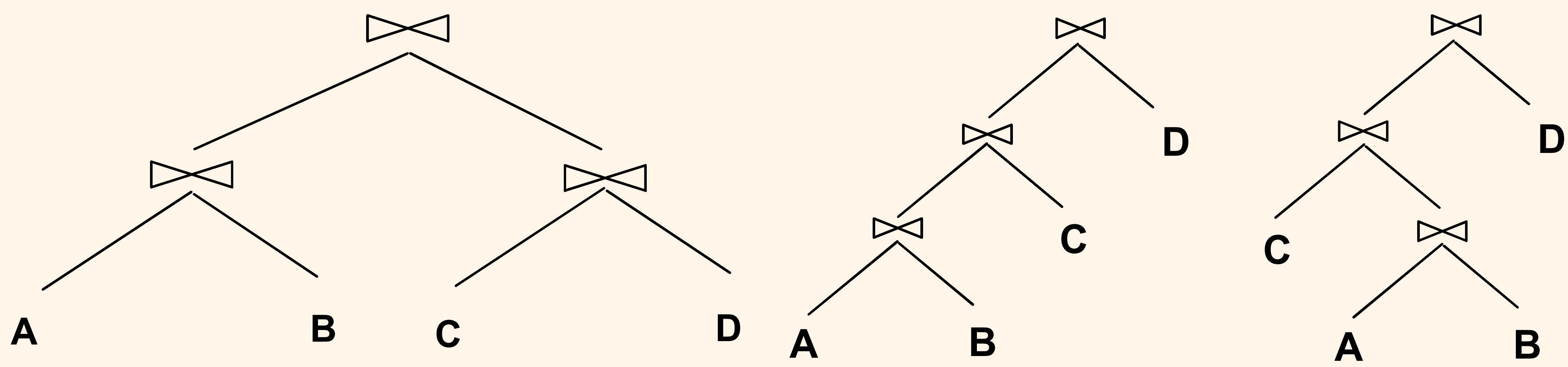
A Query Tree Illustrating Pipelining

- When a query is composed of several operators, the result of one operator is sometimes pipelined to another operator without creating a temporary relation to hold the intermediate result.



Queries Over Multiple Relations

- Fundamental decision in System R: *only left-deep join trees* are considered.
  - As the number of joins increases, the number of alternative plans grows rapidly; *we need to restrict the search space.*
  - Left-deep trees allow us to generate all *fully pipelined* plans.
    - Intermediate results not written to temporary files.
    - Not all left-deep trees are fully pipelined (e.g., SM join).



Enumeration of Left-Deep Plans

- Left-deep plans differ only in the order of relations, the access method for each relation, and the join method for each join.
- Enumerated using N passes (if N relations joined):
  - Pass 1: Find best 1-relation plan for each relation.
  - Pass 2: Find best way to join result of each 1-relation plan (as outer) to another relation. *(All 2-relation plans.)*
  - Pass N: Find best way to join result of a (N-1)-relation plan (as outer) to the N'th relation. *(All N-relation plans.)*
- For each subset of relations, retain only:
  - Cheapest plan overall, plus
  - Cheapest plan for each *interesting order* of the tuples.

Enumeration of Plans (Contd.)

- ORDER BY, GROUP BY, aggregates etc. handled as a final step, using either an `interestingly ordered' plan or an addional sorting operator.
- An N-1 way plan is not combined with an additional relation unless there is a join condition between them, unless all predicates in WHERE have been used up.
  - i.e., avoid Cartesian products if possible.
- In spite of pruning plan space, this approach is still exponential in the # of tables.

Cost Estimation for Multirelation Plans

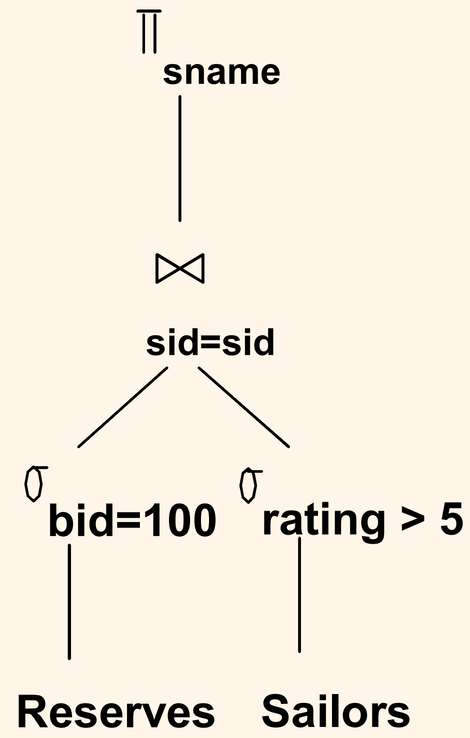
- Consider a query block:

```
SELECT attribute list
FROM relation list
WHERE term1 AND ... AND termk
```

- Maximum # tuples in result is the product of the cardinalities of relations in the FROM clause.
- *Reduction factor (RF)* associated with each *term* reflects the impact of the *term* in reducing result size. *Result cardinality* = Max # tuples * product of all RF's.
- Multirelation plans are built up by joining one new relation at a time.
  - Cost of join method, plus estimation of join cardinality gives us both cost estimate and result size estimate

Example

Sailors:
  B+ tree on *rating*
  Hash on *sid*
Reserves:
  B+ tree on *bid*



- Pass1:
  - *Sailors*: B+ tree matches *rating>5*, and is probably cheapest. However, if this selection is expected to retrieve a lot of tuples, and index is unclustered, file scan may be cheaper.
    - Still, B+ tree plan kept (because tuples are in *rating* order).
  - *Reserves*: B+ tree on *bid* matches *bid=100*; cheapest.
- Pass 2:
  - We consider each plan retained from Pass 1 as the outer, and consider how to join it with the (only) other relation.
    - e.g., *Reserves as outer*: Hash index can be used to get Sailors tuples that satisfy *sid* = outer tuple's *sid* value.

Nested Queries

- Nested block is optimized independently, with the outer tuple considered as providing a selection condition.
- Outer block is optimized with the cost of `calling' nested block computation taken into account.
- Implicit ordering of these blocks means that some good strategies are not considered. *The non-nested version of the query is typically optimized better.*

```
SELECT S.sname
FROM Sailors S
WHERE EXISTS
   (SELECT *
    FROM Reserves R
    WHERE R.bid=103
    AND R.sid=S.sid)
```

Nested block to optimize:

```
SELECT *
FROM Reserves R
WHERE R.bid=103
   AND S.sid= outer value
```

Equivalent non-nested query:

```
SELECT S.sname
FROM Sailors S, Reserves R
WHERE S.sid=R.sid
  AND R.bid=103
```

Summary

- Query optimization is an important task in a relational DBMS.
- Must understand optimization in order to understand the performance impact of a given database design (relations, indexes) on a workload (set of queries).
- Two parts to optimizing a query:
  - Consider a set of alternative plans.
    - Must prune search space; typically, left-deep plans only.
  - Must estimate cost of each plan that is considered.
    - Must estimate size of result and cost for each plan node.
    - *Key issues*: Statistics, indexes, operator implementations.

Summary (Contd.)

- Single-relation queries:
  - All access paths considered, cheapest is chosen.
  - *Issues*: Selections that *match* index, whether index key has all needed fields and/or provides tuples in a desired order.
- Multiple-relation queries:
  - All single-relation plans are first enumerated.
    - Selections/projections considered as early as possible.
  - Next, for each 1-relation plan, all ways of joining another relation (as inner) are considered.
  - Next, for each 2-relation plan that is `retained', all ways of joining another relation (as inner) are considered, etc.
  - At each level, for each subset of relations, only best plan for each interesting order of tuples is `retained'.